

SPATIAL-TEMPORAL ANALYSIS OF MALARIA IN ENDEMIC AREAS OF PARAGUAY, 2002-2006

ANÁLISIS ESPACIO-TEMPORAL DE LA MALARIA EN ZONAS ENDÉMICAS DEL PARAGUAY, 2002-2006

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ABSTRACT

In the 60s, malaria cases were notified in the 90% of the Paraguayan territory, mainly affected by the transmission of *Plasmodium vivax*. Currently, malaria persistence is reported in only 3 out of 17 departments as a result of continuous operational control activities performed since 1959. The information on human cases has been registered periodically (monthly) from 2002 to 2006. NOAA and Spot Vegetation satellite images, obtained in this period of time to be used for spatial and temporal analysis of malaria cases, were evaluated to determine possible environmental risk factors associated to areas with persistence of disease cases. The region under study involves the districts with the higher number of cases and is also characterized by the presence of a big lake named "Yguazu" that is associated to a hydroelectric dam. These space technologies allowed the assessment of the spatial-temporal evolution of the lake area in the period under study demonstrating a relation of the environmental parameters with the incidence of malaria during those years. A high-spatial resolution remote sensing is needed to evaluate if temporary and relatively small ponds could be associated to the dynamic of the lake and with the dam, creating a variable environment where mosquitoes can thrive thus contributing to the transmission and spread of this disease.

RESUMEN

En los años 60, el 90% del territorio paraguayo notificaba casos de malaria, transmitido principalmente por el *Plasmodium vivax*. En la actualidad, la persistencia de la malaria se encuentra en sólo 3 de los 17 departamentos, como resultado de las continuas actividades de control de vectores realizadas desde 1959. Para el análisis se utilizaron los casos humanos registrados mensualmente entre los años 2002 y 2006. Para el análisis espacio-temporal se utilizaron imágenes satelitales NOAA y *Spot Vegetation*, obtenidos en el mismo período de tiempo, con el fin de determinar posibles factores de riesgo ambientales asociados a las áreas con persistencia de casos de la enfermedad. La región de estudio comprende los distritos con mayor número de casos y se caracteriza también por la presencia de un gran lago llamado "Yguazú" que se asocia a una represa hidroeléctrica. Esta tecnología espacial permitió la evaluación de la dinámica espacio-temporal de la zona del lago, que demuestra una relación de los parámetros ambientales con la incidencia de la malaria durante esos años. Una alta resolución de teledetección espacial es necesaria para evaluar si los charcos de agua temporales y relativamente pequeños podrían estar asociados a la dinámica del lago y la represa, creando un entorno variable donde los mosquitos vectores puedan prosperar contribuyendo así a la transmisión y propagación de esta enfermedad.

Keywords: malaria and satellites, spatial technology, malaria modelling, malaria and environmental monitoring, endemic malaria in Paraguay

Palabras clave: malaria, factores de riesgo, procesamiento de imagen asistida por computador, control de vectores.

INTRODUCTION

Malaria cases are reported in 21 Latin American and Caribbean countries with the 91 percent of all cases in the nine countries that share the Amazon rainforest. Approximately 137 million people live in areas at risk of malaria in the Americas, which represents ~4% of the world population at risk. Since the 1950's and the advent of malaria eradication programs, the countries in the Region of the Americas have developed extensive expertise in indoor spraying of insecticides for the control of malaria transmission. The Americas had an estimated 4 million malaria cases in 2002 but the malaria incidence declined 20% between 2000 and 2006, while mortality decreased 70% over the same period (Breman, 2006; WHO-PAHO 2007; WHO, 2008). The unique features of the region are characterized by the existence of many areas of low transmission, a high proportion of cases caused by *Plasmodium vivax*, and a number of countries where the disease is already in elimination. Within the same country, some areas can be malaria free, while others can be in the control or elimination stage, requiring strong stratification efforts and targeted approaches. According to WHO, Mexico is in the pre-elimination stage, while Argentina, El Salvador, and Paraguay, are in the elimination stage. Jamaica is in the prevention of reintroduction stage. The remaining 17 countries in the region are currently in the control stage and need to scale-up appropriate preventive and case management interventions to all populations at risk and sustain this level of control (WHO, 2008).

In the 60s, the notification of malaria cases was in 90% of the Paraguayan territory, mainly affected by the transmission of *Plasmodium vivax* (the elimination of autochthonous transmission of *P. falciparum* was 13 years ago). Actually, the persistence is in 3 out of 17 departments as a result of continuous operational control activities performed since 1959 and the country is considered in the elimination stage. Control activities rely mainly on active case detection (diagnosis and treatment of malaria cases) and management of active foci (preventing mosquito bites, and killing mosquitoes based in adult mosquito control with indoor residual spraying (IRS) and sometimes a combination with space spraying) and it is encouraged to push towards bringing local transmission to zero.

Malaria parasites are transmitted by female mosquitoes belonging to the genus *Anopheles*, the species in Paraguay are *An. darlingi*, *An. albitarsis* and

An. strodei. About 100 to 150 eggs are laid on the water level during oviposition. Each type of mosquito prefers to lay its eggs in a particular kind of water. Some will lay only in fresh, clear, water with some shade, others only in brackish water; some may even lay eggs in very small quantities of water, such as a hoof-print. The type of sites most likely to harbour the larvae of anopheline mosquitoes are: rivers, streams, ponds, lakes, swamps and marshes where larvae usually occur in vegetation around the edges. It has been described that higher than average seasonal rainfall should lead to increased cases of malaria, and that climate ensemble forecasting technique may provide early warning of malaria risks in prone regions (Thompson et al., 2006).

In this paper we describe an operational research conducted to evaluate the fluctuation of a lake area directly influenced by a hydroelectric dam as a potential environmental risk factor associated with the persistence of malaria cases in two out of the three endemic departments in Paraguay. The study was focused in a big lake named "Yguazu" and space technology was apply to assess the correlation of the spatio-temporal evolution of the lake area from 2002 to 2006 and the incidence of malaria during those years using the information of human cases registered periodically (monthly).

MATERIALS Y METHODS

Selection of study villages and description of the area. The area lies in the Oriental Region of Paraguay and in two endemic departments, Caaguazú and Alto Paraná. The population (705,133 inhabitants) is largely rural and the people are engaged mainly in agriculture and cattle. The area has an extension of 26,279 km², the annual temperature in the region is approximately 22°C and Caaguazú is considered the rainiest department of the country, with an annual precipitation of 1,600 millimeters. The main rainy season extends from October to the end of March, the hottest months are December, January and February. The coldest months are July and August. The lake area is approximately 2,826 km² and the region under study surrounding the lake is 7,850 km². This area is considered of high risk: localities with Annual Parasitic Index (API) > 5 cases per 1,000 habitants, with autochthonous cases detected predominantly in the indigenous communities living around the lake.

Data for spatial-temporal analysis. The information on human cases, registered monthly from 2002 to 2006 was used. NOAA NDVI (vegetation index), temperature and Spot Vegetation decadal products (images) for spatial and temporal analysis were evaluated to determine possible environmental risk factors, in addition two factors such as precipitation and altitude, associated to areas with persistence of malaria cases:

- Correlation with the variables gathered from the environmental products (mean values obtained with precipitation, vegetation, temperature and altitude) and API (Annual Parasitic Index).
- Evaluation of the distance to the lake as a significance variable.
- Lake level fluctuation (buffer with the pixels of the lake, minimum and medium values of ROI) every 10 days during 5 years, and association with the API.

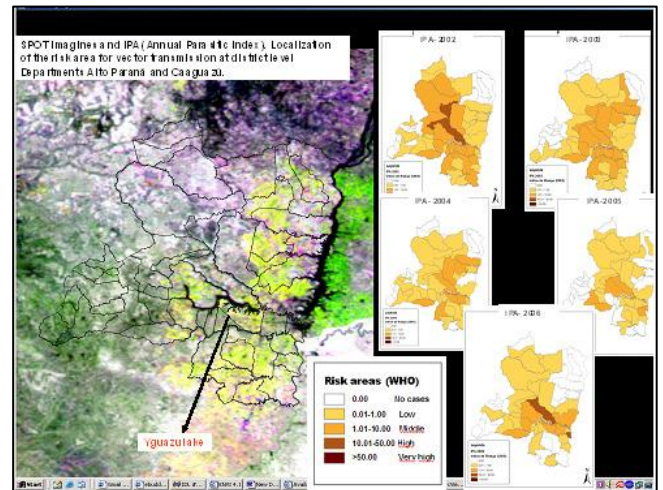


Figure 1. Satellite image of the studied area and the different levels of malaria risk.

RESULTS AND DISCUSSION

To study the correlation of malaria cases with the fluctuation of the Yguazú lake level located between the endemic districts of Caaguazú and Alto Parana departments, we studied the area with NOAA products making an association of the API (Annual Parasitic Index) and the medium values obtained from environmental variables (precipitation, vegetation, temperature and altitude). We did not observe any correlation between these environmental products and the API data and it was probably because the processed data was in a large geographic resolution (at district level). In order to get better results, the data have to be analyzed at locality level, a scale size comparable with the level of the lake.

In Figure 1, SPOT images and API (Annual Parasitic Index) are presented. The localization of risk areas for vector transmission according to WHO (no cases, low=0.01-1.0, middle=1.01-10.0, high=10.01-50.00 and very high>50.00 risk) at district level in the Departments of Alto Paraná and Caaguazú are shown. A buffer with the lake pixels was performed to explore if the distance to the lake could be an indicator to predict the incidence of cases, but no conclusive results were obtained. The fluctuation of the level lake area was performed using SPOT VEG images with temporal analysis every ten days for 5 years and it was associated with the API. Figure 2, shows the temporal evolution of API and lake level every 10 days (per month).

Figure 3, shows the level variation (level in T_N – level in T_N-1). It was observed that the lake level through the 5 years of study presented three great peaks, while the disease (the API) two high peaks (May 2002 and May 2006). The maximum peaks (incidence) observed did not represent a clear correlation. When the level of the lake increased over the mean level, no incidence of the disease was observed. On the contrary, when the lake level went below of a critical threshold, the cases of malaria remarkably increase (Fig. 3) as in March-April 2002 and March-April 2006. If we consider that the eggs and larvae of anopheline mosquitoes are laid on the water level and usually occur in vegetation around the edges of the lake, our observation could be explained from a biological point of view. When the lake level is at mean or over the mean level, the eggs and larvae are eaten by fishes and the number of adult mosquitoes decrease to a level where no transmission can occur. On the contrary, when the lake level is below a critical threshold, many ponds with vegetation surrounding the lake are observed, in accordance with the information obtained in the field from the vector control staff. The water-level fluctuation could be due to rainy seasons, but we do not discard the possibility of an involvement of the hydroelectric dam mechanical manipulation, considering the high peaks of transmission observed mainly in September and November.

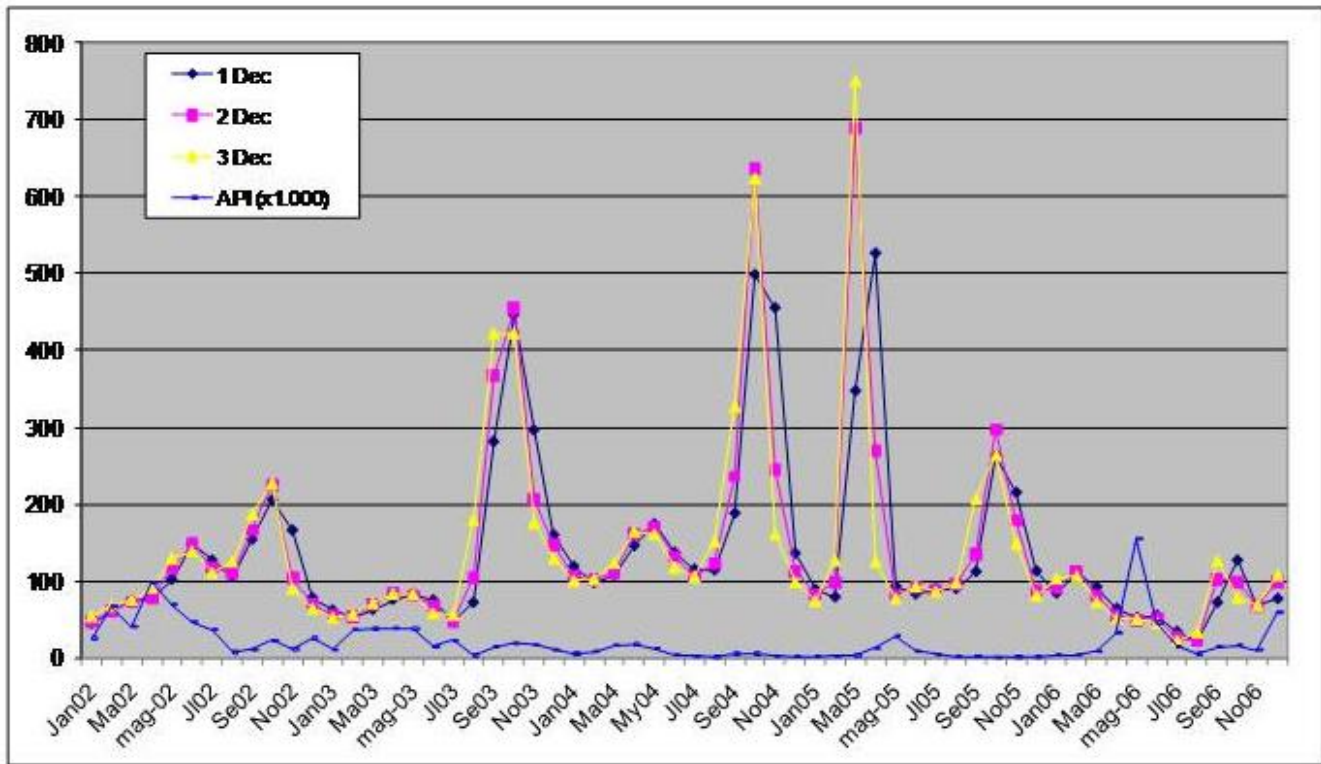


Figure 2. Monthly variation of the lake level and the API index.

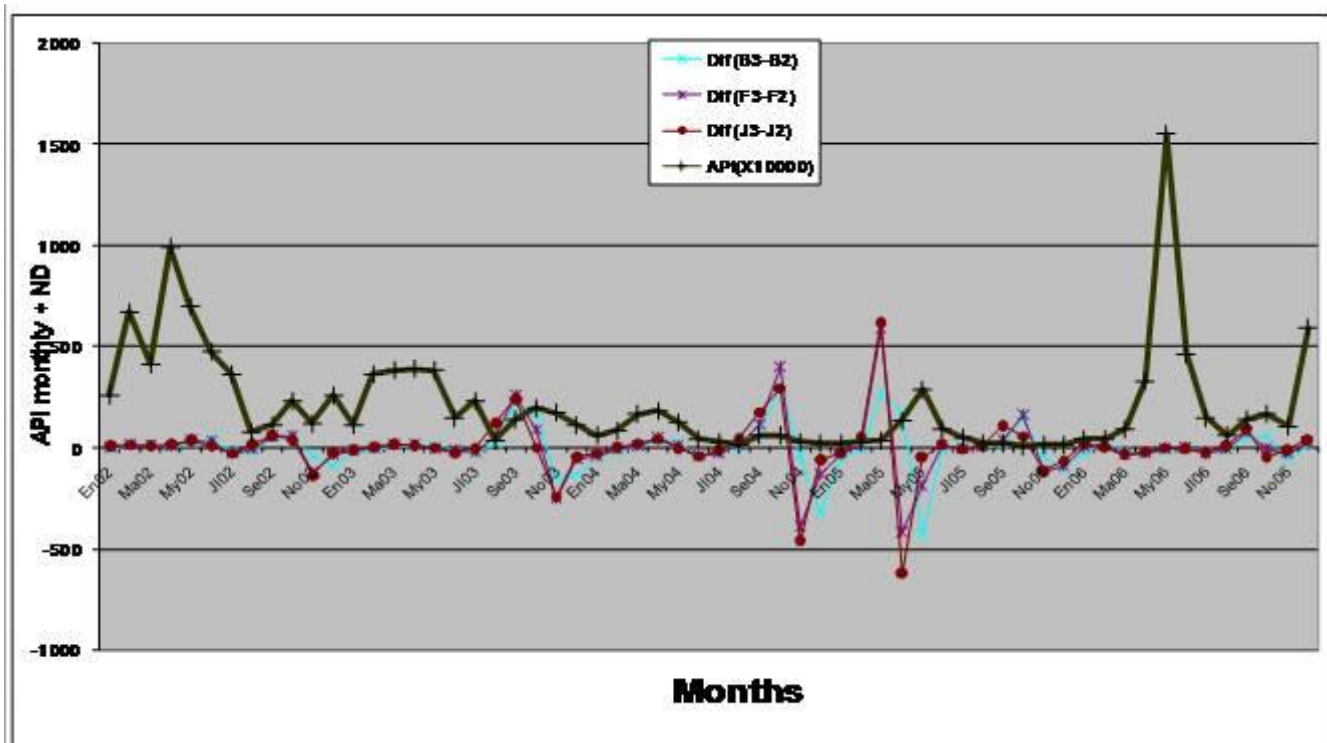


Figure 3. Correlation between the API index and the lake level fluctuations with respect to a lake level threshold.

Remotely sensed monitoring of ponds and their characteristics, if properly coordinated with in-situ monitoring and if implemented in close collaboration with entomologists, should facilitate the study of mechanisms involved in malaria transmission, as it was observed for other diseases (Vignolles *et al.*, 2009). Our results must be complemented with a high-spatial resolution remote sensing to evaluate if temporary and relatively small ponds could be associated to the dynamic of the lake and with the dam, creating a variable environment where mosquitoes can thrive and thus contribute to diffusion and transmission of this disease.

CONCLUSIONS

Earth-observing satellites have provided an unprecedented view at the land level but have been exploited relatively little for the measurement of environmental variables of particular relevance to epidemiology. Since 1960-70, civilian satellites launched for earth observation have been providing information to measure or evaluate geo-climatic and anthropogenic factors related to malaria transmission and burden. Remotely sensed data gathered for several civilian or military studies have allowed the setup of entomological, parasitological, and epidemiological risk models and maps for rural and urban areas (Machault *et al.*, 2009).

The aim of this study was to investigate, using space technologies, a problematic area where control measures proved unsuccessful (active search with permanent cases detected). A focal investigation was undertaken in areas of persistent malaria transmission to determine why the disease is not responding to the measures being applied and to identify the best approaches to control the disease spread. Although further studies with longer periods of observation and images taken at a lower pixel level are needed, the

results obtained indicate that environmental parameters or situations other than those classically measured for malaria have to be analyzed when no responses to elimination measures are obtained. On the basis of the results obtained in this study, it is also proposed that the number of malaria cases would be a better epidemiological marker than API.

Operational research, including remote sensing and study of space and time dynamics of malaria, is necessary in Paraguay for taking appropriate decisions and prioritizing interventions considering that the country is at the elimination stage and it is encouraged to push towards bringing local transmission to zero. Remote sensing is a suitable tool for optimizing planning, efficacy and efficiency of malaria control considering that, within the same country, some areas are malaria free while others are in the control or elimination stage requiring strong stratification efforts and targeted approaches.

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